Stratocumulus to Cumulus Transition CPT

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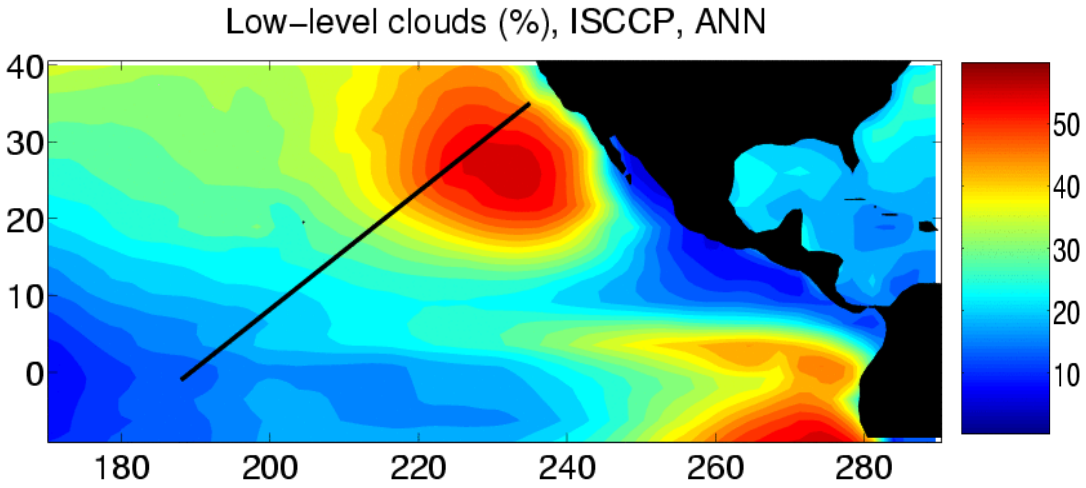
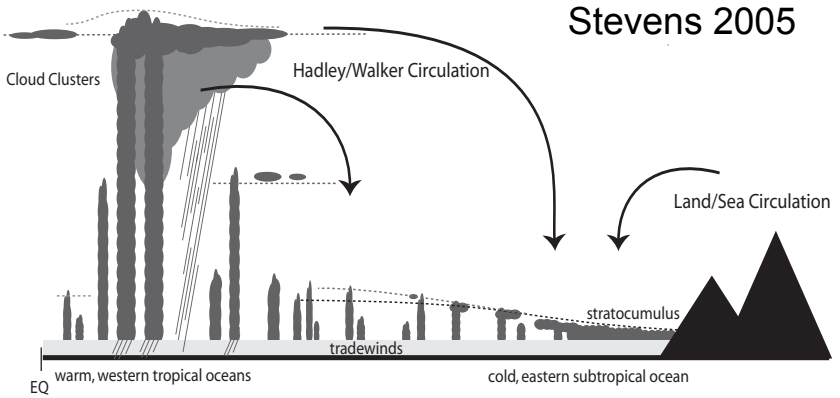
Goal: Improve the representation of the cloudy boundary layer in NCEP GFS and NCAR CAM5 with a focus on the subtropical stratocumulus to cumulus (Sc-Cu) transition





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Motivations for CPT

NCEP

- Vision: Can GFS become a unified operational weather-climate model for daily to interannual forecasting & reanalysis?
- Diagnose and improve clouds in operational GFS
- Evaluate free-running coupled GFS with climate model metrics
- Use single-column GFS as testbed for new parameterization ideas (ShCu mods, pdf cloud fraction, EDMF turbulence)

NCAR

- CESM/CAM5 has new moist physics & aerosol parameterizations that change cloud climatology & feedbacks
- Their interaction is inadequately understood and suboptimal; CAM5 microphysics is complex, sensitive to model timestep

CPT Current Main Tasks

a) Better coupled/uncoupled climate diagnostics for GFS (UCLA, NCEP, NCAR)

b) GASS Sc/Cu cases with NCAR and NCEP SCMs, and LES (UW, NCAR, NCEP, JPL)

c) Test SCM-suggested modifications in short coupled GFS runs (NCEP, UCLA, UW)

d) Development/testing of PDF cloud and new convection/ turbulence schemes (LLNL, NCAR, NCEP)

e) Development/testing of EDMF turb. param. in NCEP, NCAR (JPL, NCAR, UW, NCEP)

$$\overline{w'\varphi'} = -k\frac{\partial\bar{\varphi}}{\partial z} + M(\varphi_u - \bar{\varphi})$$

Siebesma & Teixeira, 2000

Focus of this talk: NCEP, last 6 months, GFS data-assim tests

GFS2011+MOM4 climate diagnostics highlights

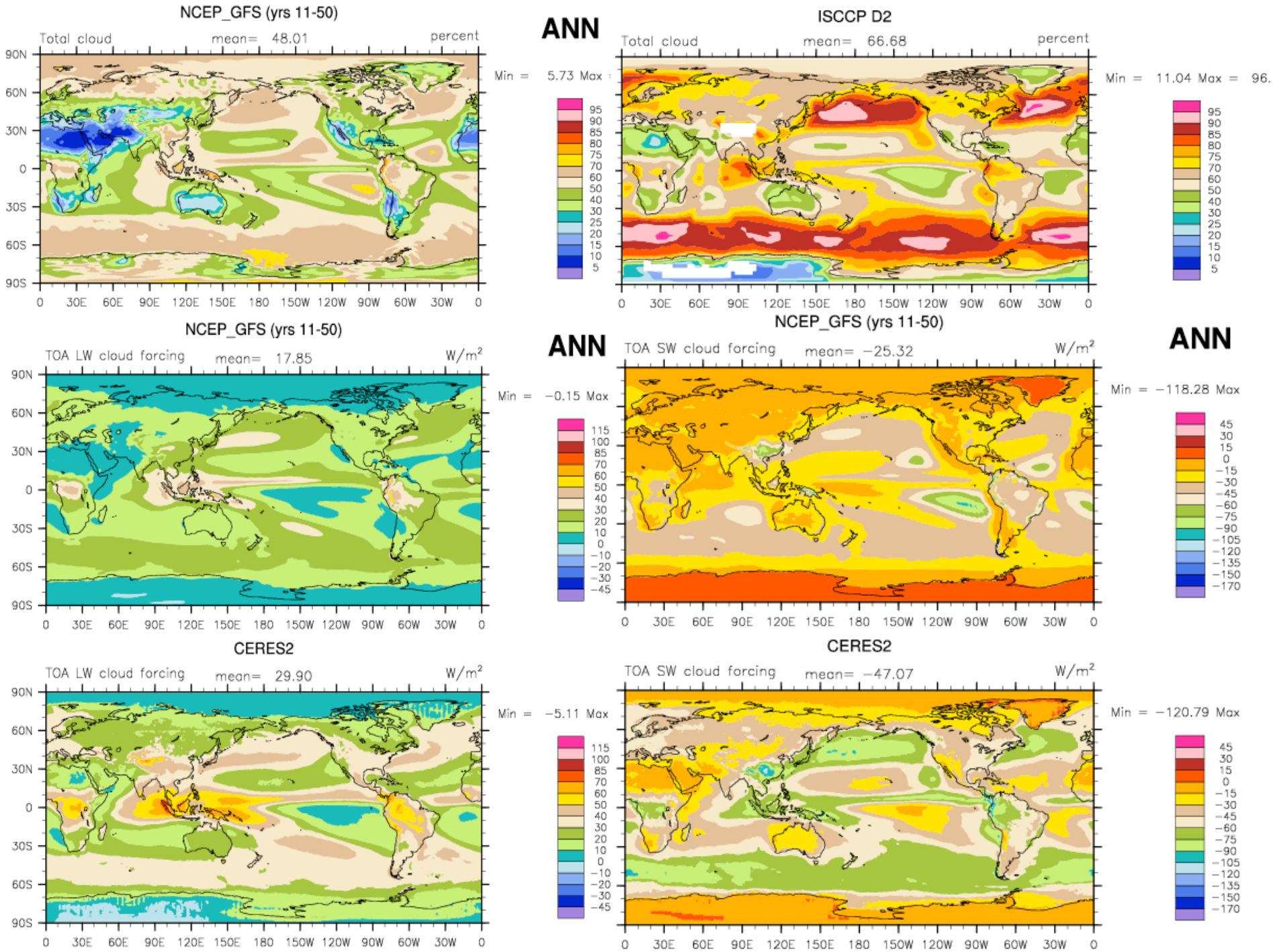
Very good overall climate except large compensating errors:

- Spurious energy loss of ~10 W m^{-2}, split between atmosphere and ocean models.
- Too little low and high cloud over most regions, allowing ~10 W m^{-2} net radiation into the top of the atmosphere.

These biases are also present in CFSv2.

Unlike prior GFS versions, GFS2011 has subtropical stratocumulus regions but they are displaced offshore.

See Xiao et al. (2012) for details. Yoo and Li (2012) also analyzed clouds but not CRF in 2007 version of GFS.


NCEP_GFS (yrs 11-50)
Total cloud
mean= 48.01
percent
ANN
ISCCP D2
Total cloud
mean= 66.68
percent
Min = 5.73 Max
Min = 11.04 Max = 96.
NCEP_GFS (yrs 11-50)
TOA LW cloud forcing
mean= 17.85
W/m²
ANN
TOA SW cloud forcing
mean= −25.32
W/m²
ANN
Min = −0.15 Max
Min = −118.28 Max
CERES2
TOA LW cloud forcing
mean= 29.90
W/m²
CERES2
TOA SW cloud forcing
mean= −47.07
W/m²
Min = −5.11 Max
Min = −120.79 Max
90N
60N
30N
0
30S
60S
90S
0 30E 60E 90E 120E 150E 180 150W 120W 90W 60W 30W 0

Strategy for reducing these biases in GFS2011

- Single-column modeling of benchmark cases vs. LES and observations to help isolate issues.
- Short global coupled simulations
- Data-assimilation weather forecast tests.

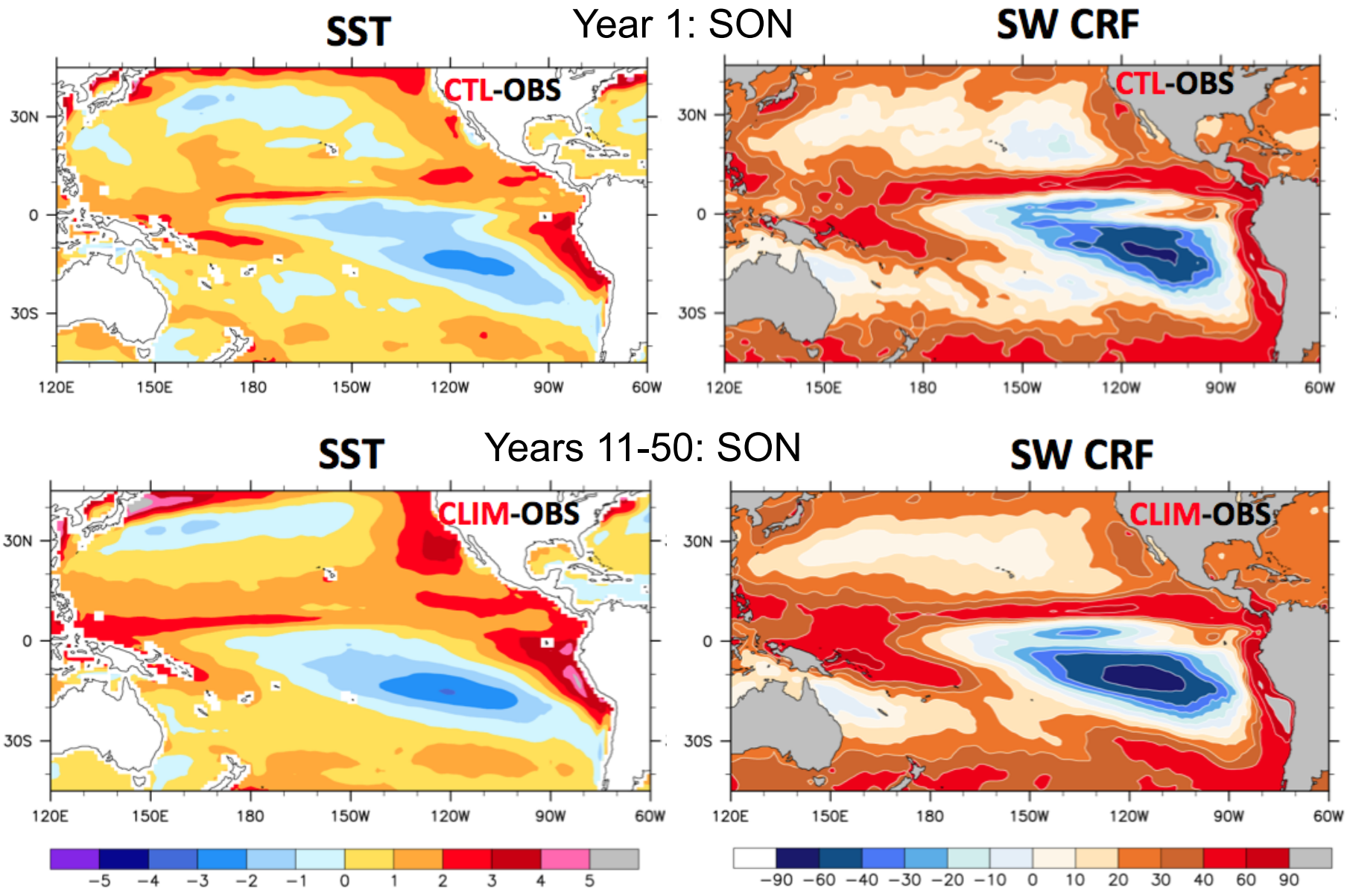
Changes suggested:

- Shallow cumulus scheme
- Inclusion of turbulent dissipation heating
- Unified cloud fraction scheme
- EDMF boundary-layer scheme

Microphysics?

1 year coupled GFS sensitivity runs (Sun, Han, Xiao)

- Tropical cloud/SST biases in coupled model develop fast



shortrun2 1-year coupled sensitivity run

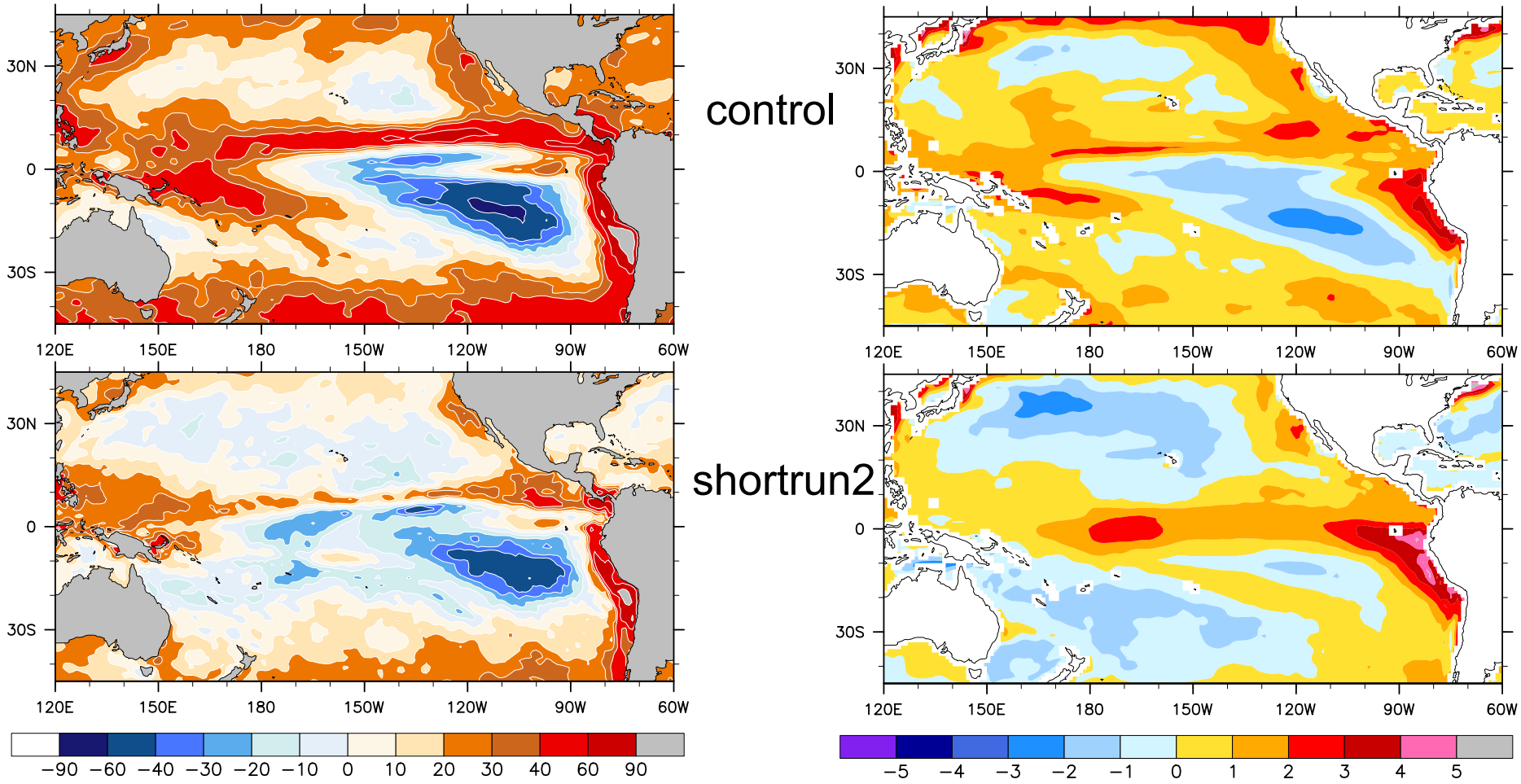
- Shallow Cu: increased entrainment,
  decreased precipitation efficiency
  new diagnosis of Cu depth
  turn off when <60 hPa deep or only in PBL
  include explicit Cu updraft cloud fraction
- Diagnose surface-layer dissipation heating from TKE eqn.
- Reduce background eddy diffusivity in capping inversion
- See Fletcher et al. (2012, near submission)

Sensitivity to ShCu changes (shortrun2)

SON Year 1

ΔSWCRF from CERES

ΔSST from HADISST



Encouraging bias reduction in SWCRF everywhere, SST in most regions

TKE dissipation heating (Han)

$$\varepsilon = \underbrace{-K_h \frac{g}{\theta_v}\frac{d\theta_v}{dz}}_{\text{buoyancy production}} + \underbrace{K_m \left|\frac{d\mathbf{u}}{dz}\right|^2}_{\text{shear production}}$$

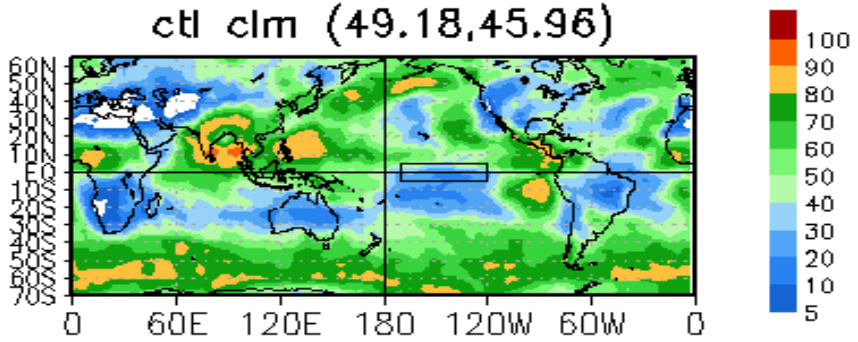
4 month coupled GFS runs	TOA (W/m^2)	SFC (W/m^2)	Difference (W/m^2)
CTL	16.2	9.6	6.6
EXP1: same as shortrun2 in Heng (dissipative heating only at the model first layer)	7.9	5.1	2.8
EXP2: same EXP1 but w/o dissipative heating	8.2	2.3	5.9
EXP3: same as EXP1 but w/ dissipative heating over whole atmospheric layer	7.8	6.9	0.9

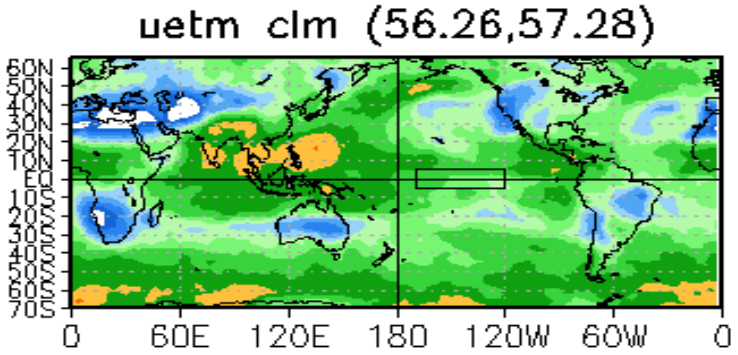
…atmospheric energy loss is now much smaller.

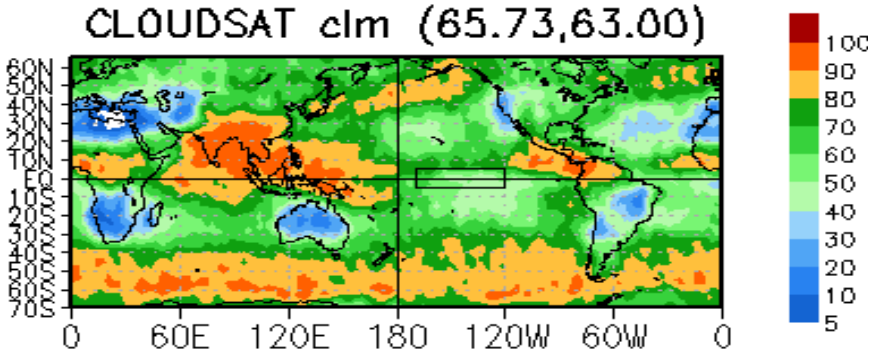
Bonus: extra heating also slightly increases hurricane intensity.

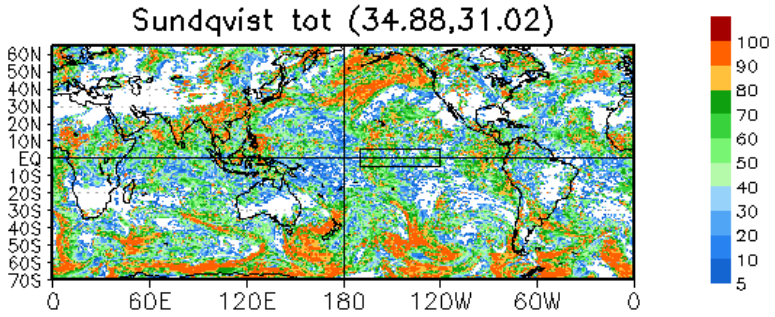
New cloud fraction scheme (Sun - Pan)

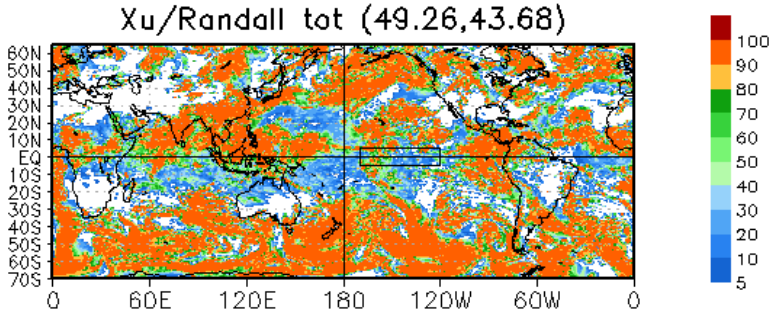
- GFS2011: different cld fractions for microphysics and radiation.
- Sun-Pan scheme replaces both: CAM5-like fixed-shape humidity PDFs for clear, cloudy regions.
- Increased cloud cover in 2-mo data-assimilation (DA) tests.











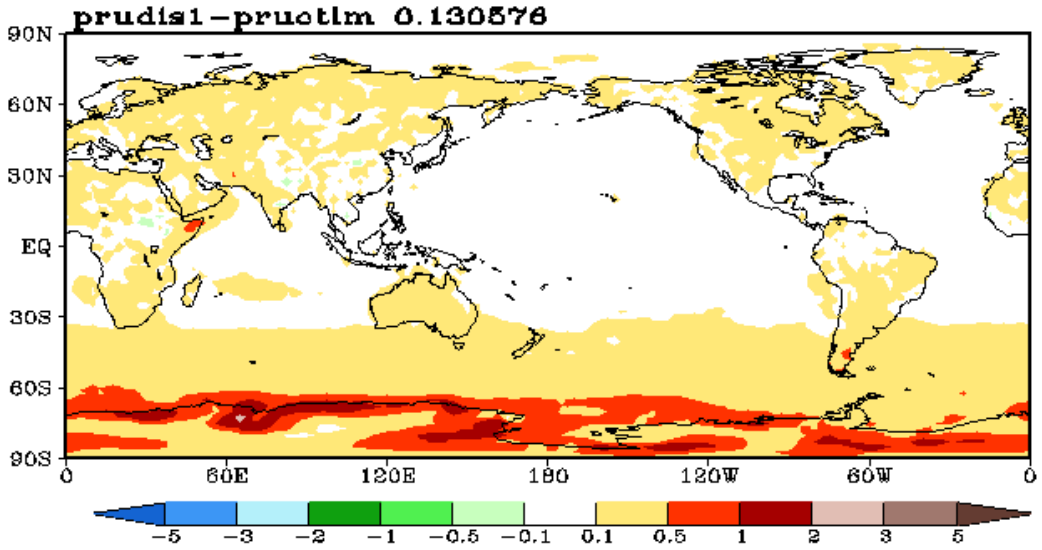
DA testing for possible GFS operational implementation

1. Surface layer dissipative heating (2.5 mo)
2. Shortrun2 physics (1 week)
3. ‘Dry’ EDMF (2 months)

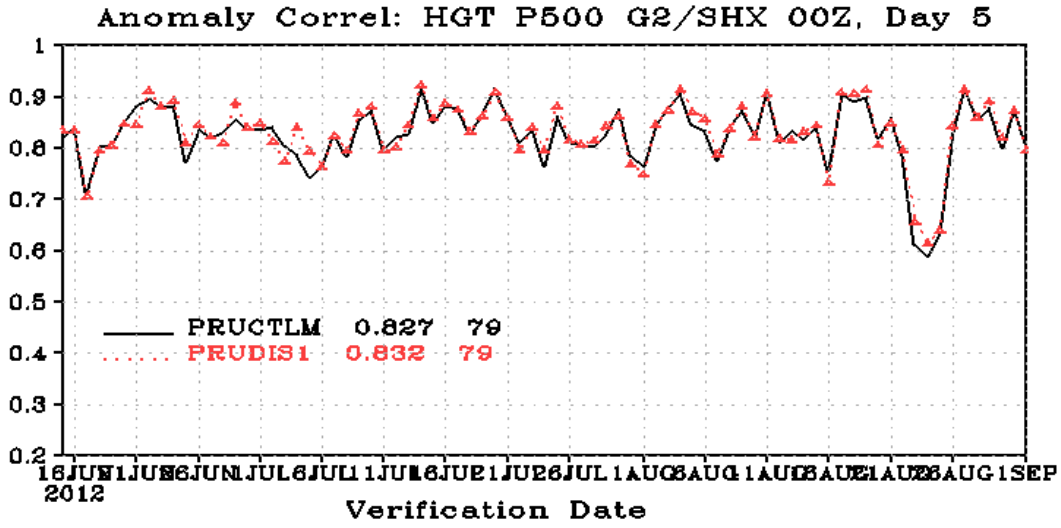
- Climate improvement was goal, but for unified weather-climate use, shouldn’t degrade weather forecasts
- These DA/forecast tests are first steps to be iterated

DISH: Dissipative heating DA/FC test

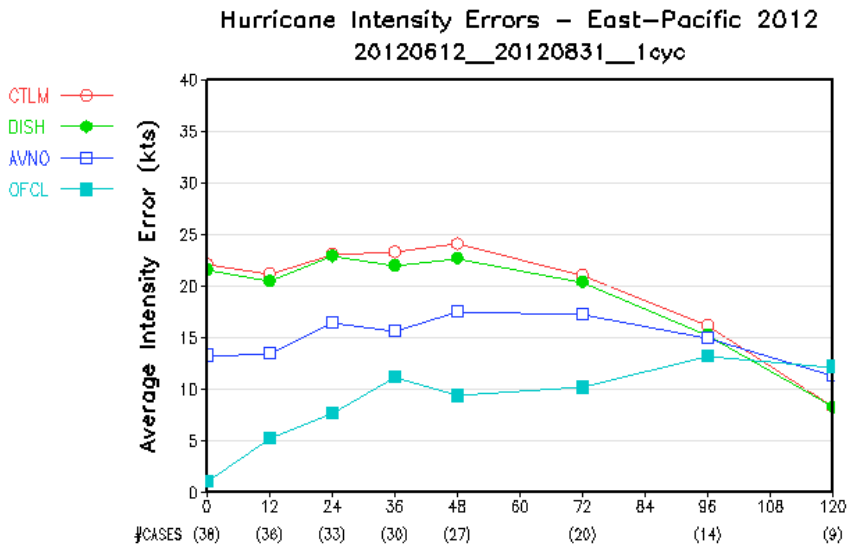
- Surface air temperature warmed under SH storm track

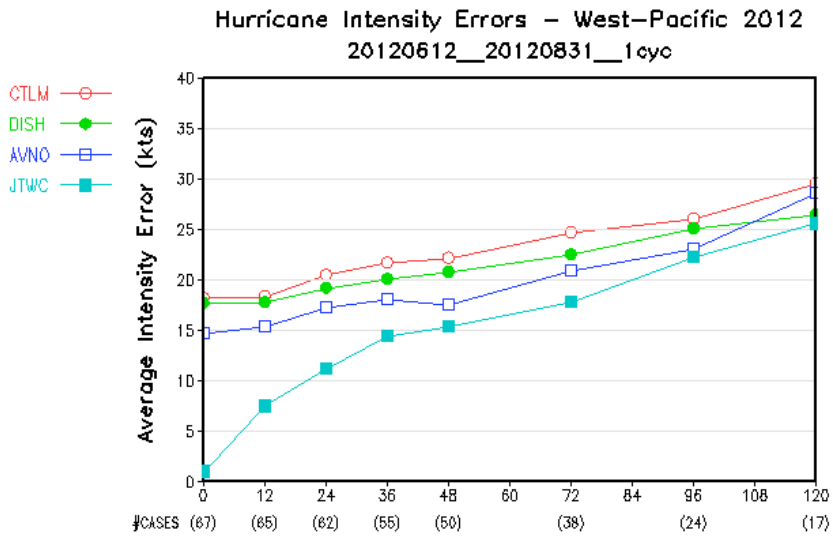


- Z500 correlation neutral in NH, slightly improved in SH



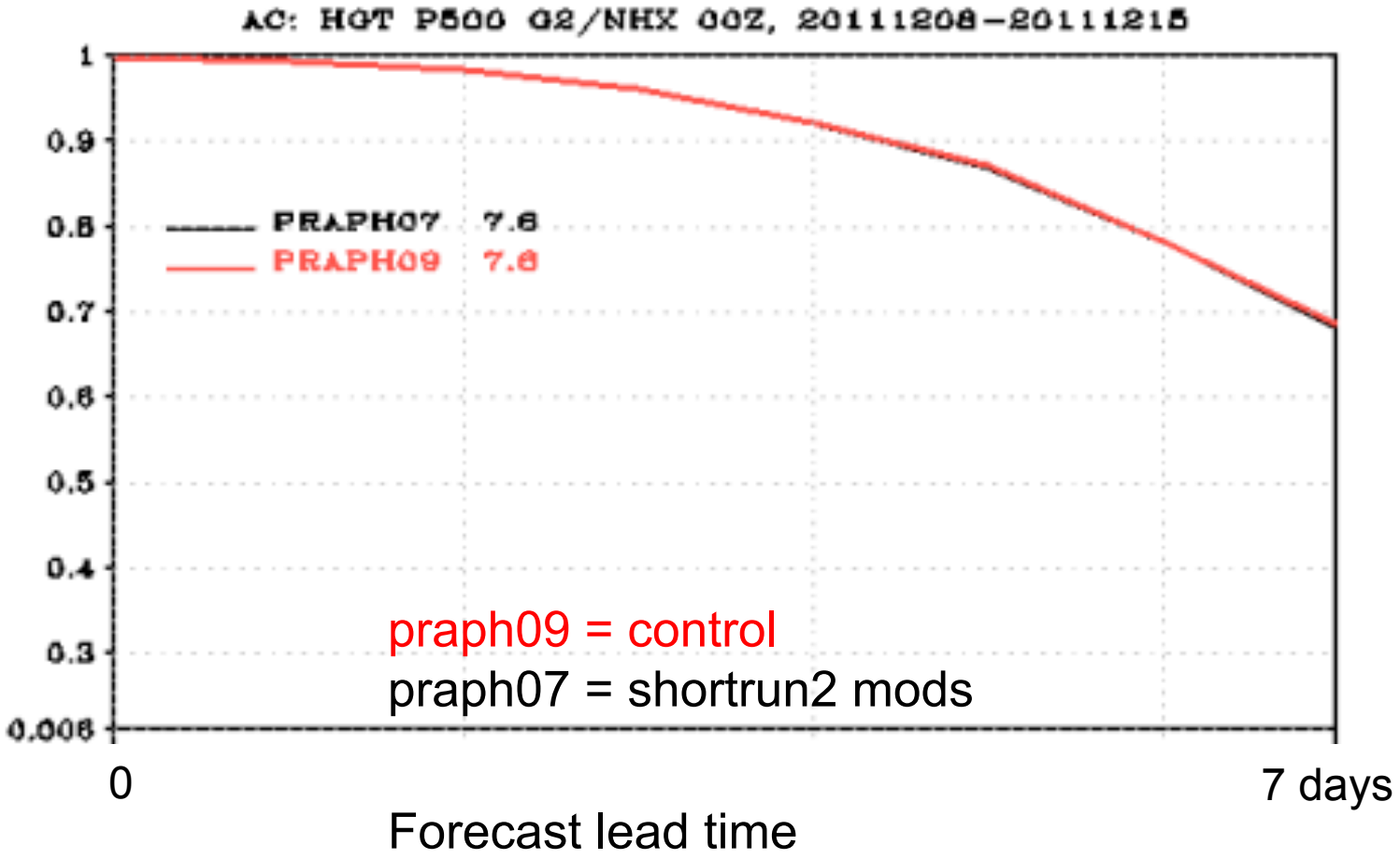
Hurricane intensity



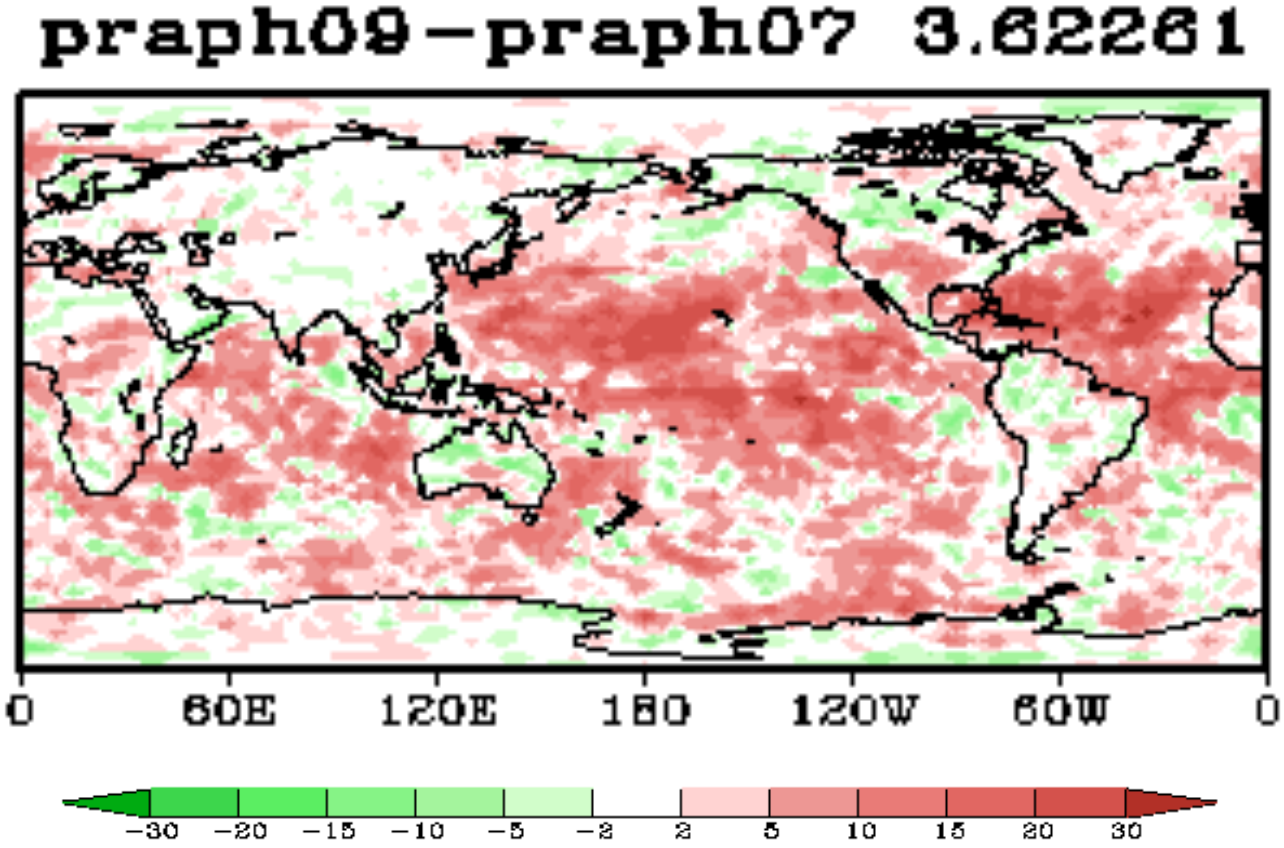


Slightly improved in Pacific, neutral in Atlantic

Shortrun2 DA/FC test
Z500 anomaly correlation

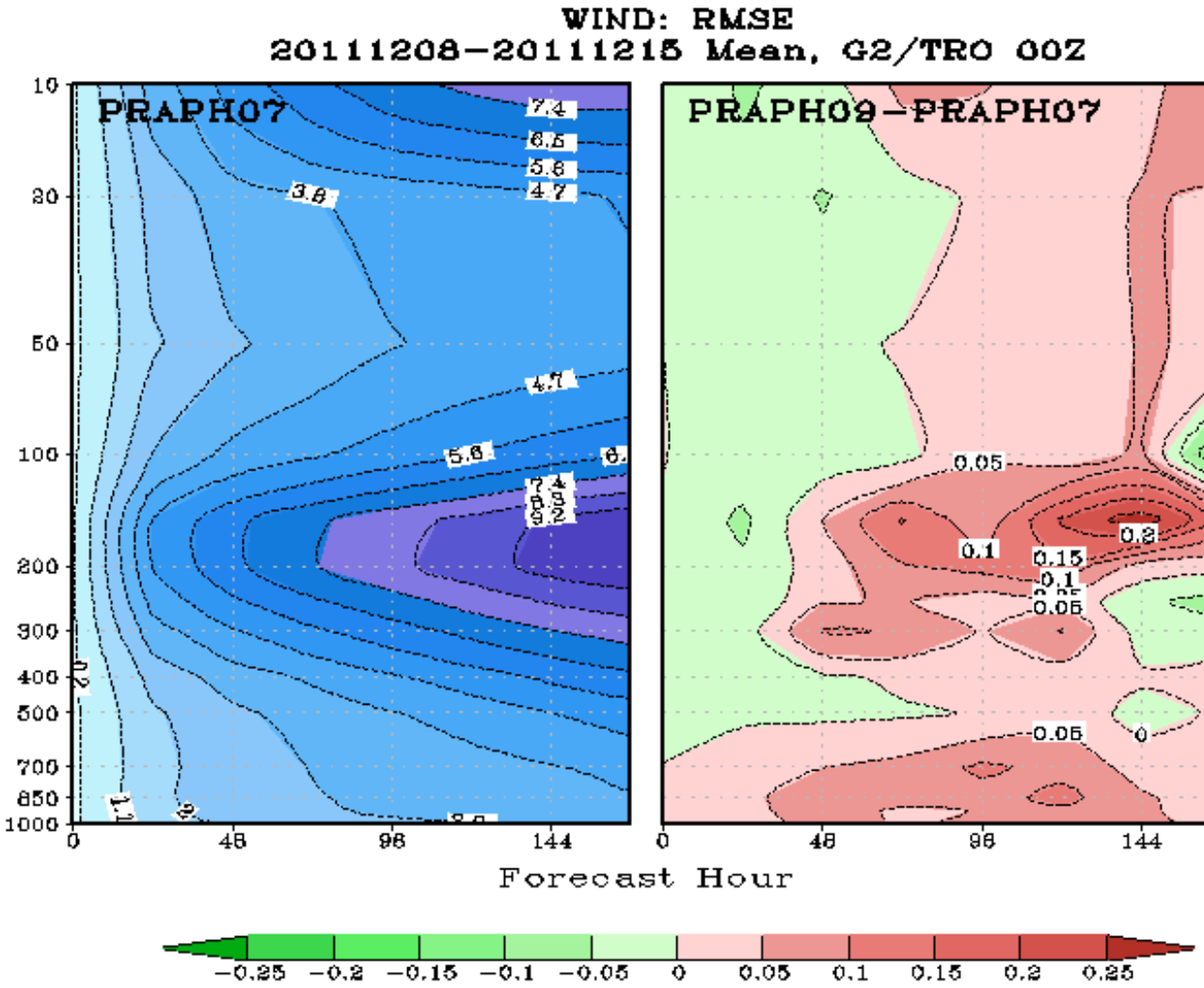


Cloud cover



- Cloud cover increases 4% (good) due to more low cloud.
- Global TOA SW↑= 5 W m^{-2}, LW↑ = -1 W m^{-2} (good)

Tropical wind errors



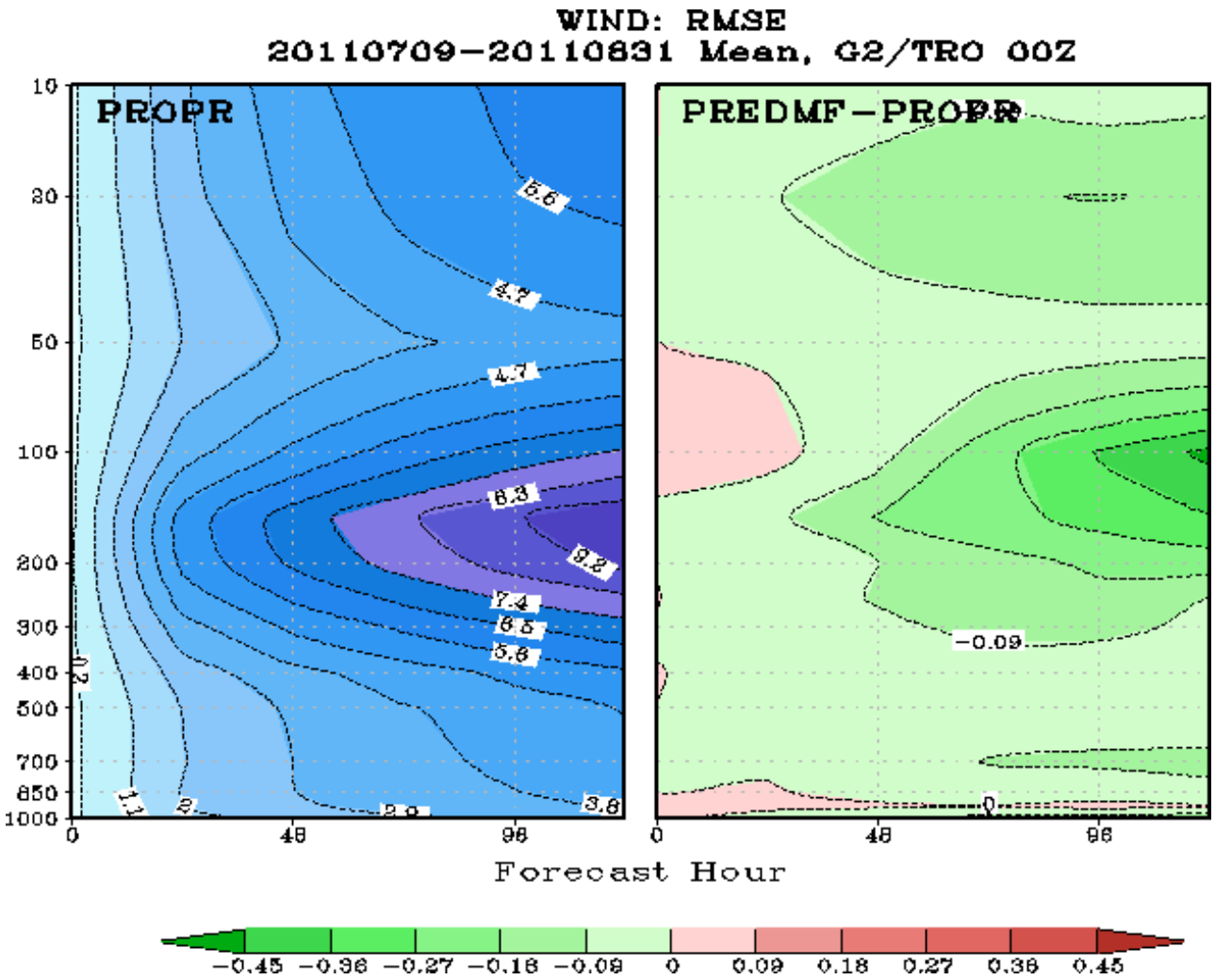
Winds slightly worsened by changes.

This might be due to changes in vertical momentum fluxes in shallow cumulus convection

We are working on an SCM-LES VMF intercomparison for a trade cumulus case.

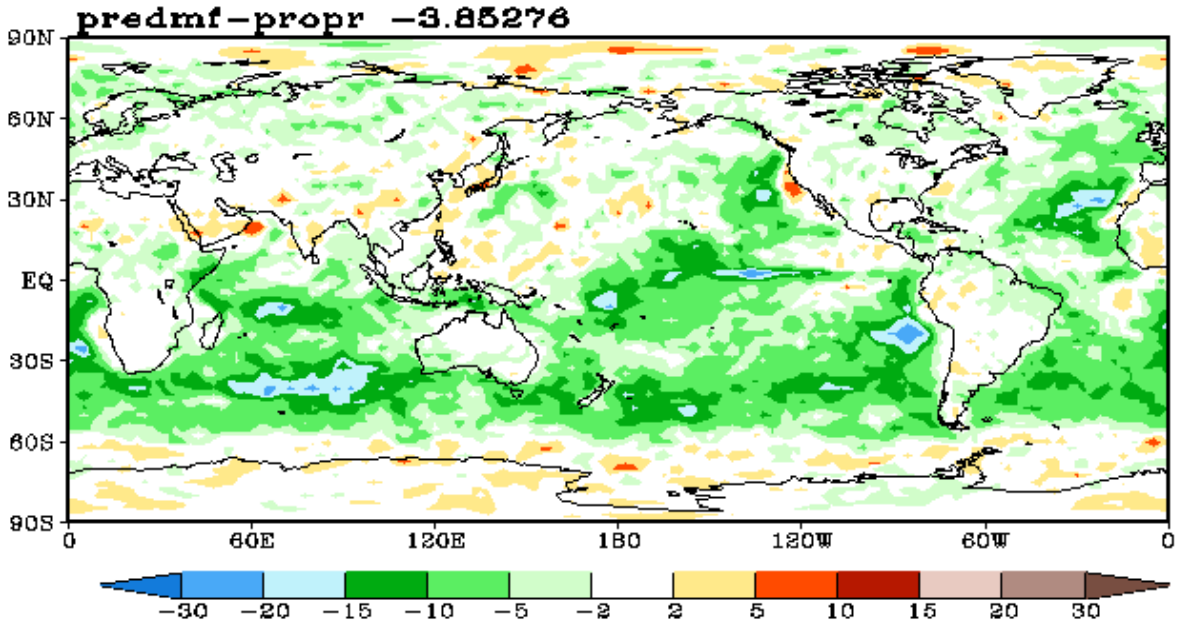
‘Dry’ EDMF

- Neutral Z500 corr, but significantly reduced wind errors

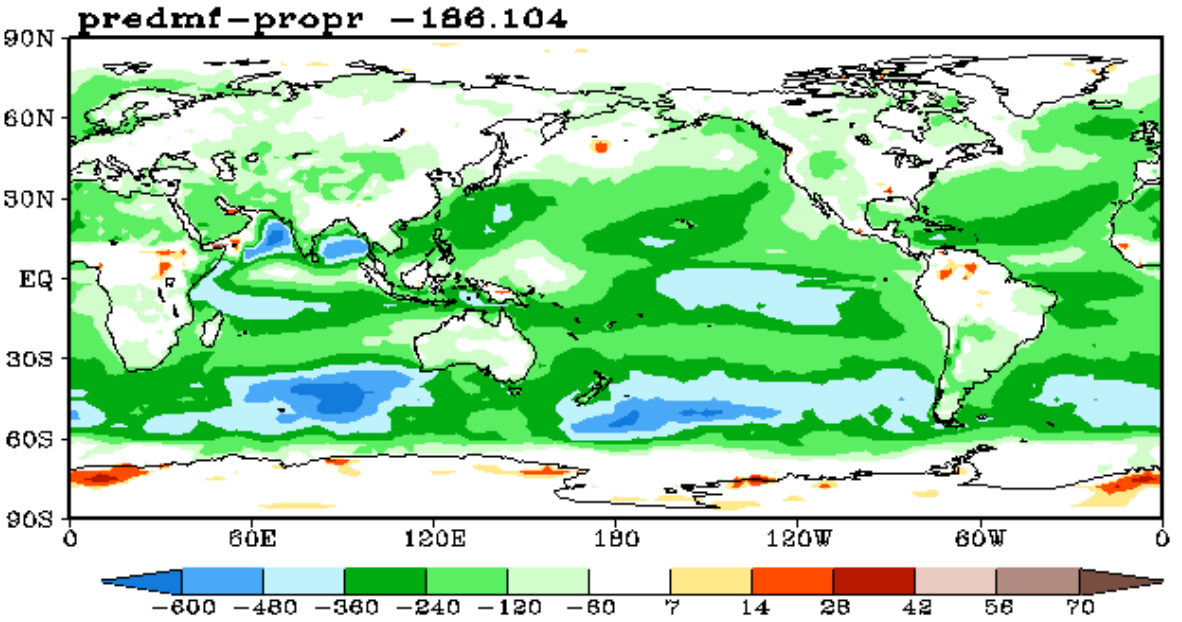


Clouds

Dry EDMF decreases cloud cover 4% and PBL height by 25% because it cannot mix through moist-adiabatic cloud layers (not good).



Dry EDMF is just a baby step to a moist implementation of EDMF proposed for Phase 2 of our CPT.



Conclusions

- The Sc-Cu CPT has identified several biases in GFS2011
  - Energy nonconservation
  - Too little cloud
  - Sc displaced too far off subtropical west coasts
- Using SCM and global testing, we have identified changes that improve the climate of GFS+MOM4.
  - Dissipation heating
  - Shallow Cu and EDMF PBL physics
  - Unified cloud fraction scheme
- Several changes tested in DA/weather forecast mode. Dissipation heating and EDMF PBL currently look best.
- Philosophical question: Adopt a change to GFS if it is weather-neutral but improves coupled climate?